EVALUATION SYSTEMS FOR ANTIAIRCRAFT ARTILLERY AND SURFACE-TO-AIR LIVE FIRING ACTIVITIES

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Abstract: *On September 19th, 1916, the first enemy airplane was shot down with 75 mm antiaircraft guns in Flămânda area. This is considered to be the birth of the Air Defense Artillery & Missile branch. In time, the branch has evolved from modified field artillery to specialized antiaircraft artillery and complex surface-to-air missile systems, the Air Defense Artillery & Missile branch thus becoming an essential component of Romania's air defense. The endowment and the development of the Romanian antiaircraft artillery after WWII imposed setting up a specialized firing range to allow training firings in safe battlefield-like conditions. Thus, on April 1st, 1950, "General de Brigadă Ion Bungescu" Training Camp and Surface-to-Air Firing Range (TIPTSA) was established, a permanent firing range, large, open and complex, the only structure in the Romanian Armed Forces to organize and host firing activities that include the third dimension – the air. TIPTSA's activity is complex and it includes mainly hosting the personnel and the equipment of the participants in the firing activities, providing the targets during the firing activities, observing and evaluating the firing activities. Evaluating the performances of the systems, as well as the personnel's training level through live firing activities during complex exercises is one of the most important links in evaluating the fighting capabilities of the units. This paper presents the evolution of the evaluation of the firing activities since the beginnings of TIPTSA, and tries to look into the future, with respect to the evaluation of the antiaircraft artillery and surface-to-air missile firings.*

Keywords: *antiaircraft artillery, antiaircraft missiles, surface-to-air missiles, antiaircraft firings, evaluation of firing activities*

1. INTRODUCTION

Antiaircraft artillery and antiaircraft / surface-to-air missiles are meant to destroy aircraft, which implies either the meeting between it and the projectile / missile, or detonating the missile in the proximity of the aircraft. Under the conditions provided by the firing range, solving the problem comes down to the meeting between the projectiles-missiles and the air targets be it target planes, flares, or airplane-towed targets.

Observing and evaluating antiaircraft firing activities demands the existence of some systems that are capable of assessing / measuring the error in range of the explosions of the projectile/missile to the air target, perpendicularly on the firing direction that contains the target. The evaluation systems have evolved in time, from the acoustic ones (AS-100, BT-23) to the radio (SRT-4) and the electro-optical ones (EOTS-F). Each of these systems has been used along the optical ones (optical observation telescope for angular difference – the TZK binoculars, the Bosch binoculars, POS-1 optical observation device de-phased firings).

Of all the evaluation systems used in the past the acoustic systems stand out, which came back to the attention of the designers along new and highly performing target plane systems. These show miss distances (zone) and miss angle (sector) of the antiaircraft firing activities.

The operating principle of the acoustic evaluation system uses the characteristics of the shock wave created around the supersonic projectile in order to determine the error of the projectile to the indicator (miss distance). The detection microphones of the indicator receive the amplitude of the shockwave. The electric signal from the microphones gives the error in range - miss distance. Each microphone has a preset code signal that indicates the sector. Both sets of impulses (zone and sector) are sent in space, received by the receiver, which after processing them indicates the zone, sector, and the number of observed firings [1].

The AS-100 and BT-23 acoustic systems used either the G.S.-RES-20604 ground station, which presents the results of the firing in 6 zone electronic counters and 4 sector electronic indicators, automatically recording them on tape, or the G.S.-REM–20300/B ground station – campaign receiving station, easy to transport and maintain, which showed the results of the firing on electronic indicators in 3 zones.

2. SYSTEMS CURRENTLY USED TO EVALUATE FIRING ACTIVITIES

2.1 Optical systems used to evaluate firing activities. For direct antiaircraft artillery firing *the TZK binoculars* are used, which are capable of:

- observing targets and the results of the firing activities;
- measuring miss distances between the burst trails and the target;
- measuring horizontal angles (within the n×360 º range) and vertical angles (within the -18º + 84º range);
- cueing the surface, air and water targets.

For off-phased firings, the *POS – 1 device* is used. It measures direction and elevation errors between explosions and targets, both for the mirror off-phasing method and the azimuth off-phasing method.

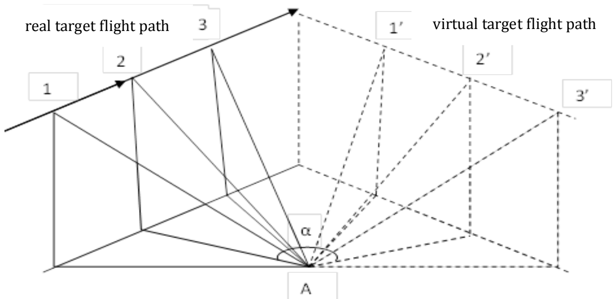

FIG.1. Firing scheme for azimuth off-phasing method by alfa angle (α)
1,2,3 – target positions, 1’,2’,3’ –imaginary points positions, A - POS-1 station point, α –azimuth off-phasing angle

The basic working procedure for the POS-1 is the scale reading of the elements of the current position of the target and of the angular differences of the bursts on the cross lines of the commander’s telescope.

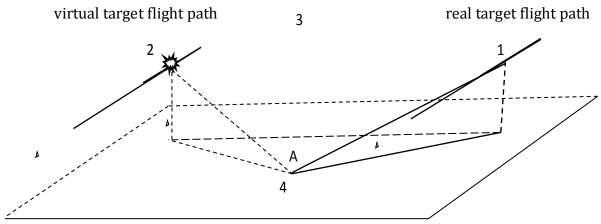

FIG. 2. Firing scheme for mirror off-phasing method
1- target, 2-imaginary point, 3- the surface of the mirror, 4 – artillery battery, A- POS-1 station point

Using two POS-1s set apart at a certain distance, we can also measure the errors in range between the bursts and the targets [2].

2.2 The electro-optical targeting system – EOTS-F. EOTS-F is meant to accurately determine the trajectories of the air targets, the errors between two air targets and between flares and an air target. Unlike the optical systems that are used, this is used for evaluating both antiaircraft artillery firing and antiaircraft/surface-to-air missile firing.

EOTS-F consists of:

- the Master Station – MS, which is mainly used to measure the trajectory and to evaluate the results of the firing activity. The other functions of the station are somehow related to this main task. The main components of the master station are MC32 front end (FE) computer, data interface of the FE computer (PDI), evaluation unit with TES and AFD sub-systems, micro-VAX (μVAX) computer, terminal operators (VT320) and the magnetic recording device.

- the cinetheodolite assemble: two bi-dimensional measuring instruments which have automated tracking devices in infrared (THIR1, THIR2), and two similar instruments which have automated tracking equipment in the visible specter (THTV1, THTV2) [2].

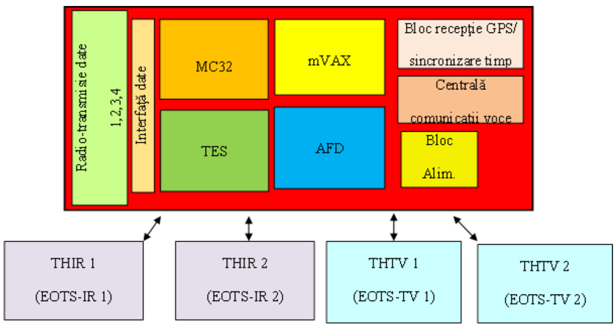

FIG. 3. EOTS-F components

The EOTS-F system is primarily based on determining the angular coordinates of a point in space using bi-dimensional measuring instruments that have a highly accurate measuring system for the azimuth and elevation angles ($2 \cdot 10^{-4}$ gons $\equiv 3.14$ mm/km), set in accurately determined positions [3]. Each cinetheodolite transmits a set of data, containing time, identification label, and position information comprising coded azimuth and elevation angles (t, no.th, α, λ). Using the implemented mathematical device the collected primary data is processed and synchronized and the spatial coordinates (x,y,z) of the tracked object are obtained for each tact of the generator related to time.

2.3 The numerical determination of the tri-dimensional coordinates with the EOTS-F. Numerically determining the position of the target, in relation to a reference position existing in the firing range, is based upon the triangulation method and allows obtaining the coordinates of the flying object through geometric calculus using the angles of the optical sighting /tracking axes of the target in azimuth and elevation of the theodolites.

The numerical method took into account several working hypothesis that refer to the existing situation in Capu-Midia firing range, and these are:

- the position of the cinetheodolites in Capu Midia firing range are accurately determined, the reference point having the coordinates [x = 0, y = 0, z = 14.093];
- the possible position to set the cinetheodolites are aligned and have an azimuth of 183°;
- the distances between the possible positions to set the cinetheodolites are accurately determined.

The geometric calculus, according to the situation corresponding to the working hypothesis in which the firing point PT is between the two cinetheodolites IR, is based on the representation depicted in Fig.4.

The case in which the firing point PT is situated south of the two cinetheodolites is similar.

Thus, we know:

- theodolite THIR1 in reference position→ P_1 (0,0);
- theodolite THIR2 in reference position P_2 on line183°;
- distance $P_1P_2 = D$;
- azimuth angles θ_1 and θ_2 of the THIR1 and THIR2 theodolites.

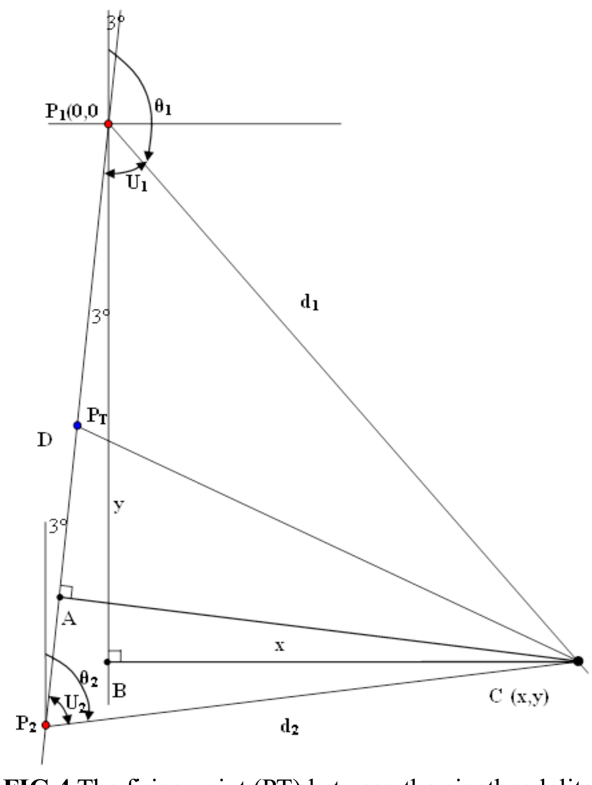

FIG.4 The firing point (PT) between the cinetheodolites

We must find the position of the traget: C (x, y).

We mark: $U_1 = 183 - \theta_1$ (1)

$U_2 = \theta_2 - 3$ (2)

The right-angled triangles P_1AC and P_2AC give us:

$$tg(U_1) = \frac{AC}{P_1A} \tag{3}$$

$$tg(U_2) = \frac{AC}{P_2A} \tag{4}$$

Replacing U_1 and U_2, we get:

$$P_1A = \frac{AC}{tg(183-\theta_1)};\ P_2A = \frac{AC}{tg(\theta_2 - 3)} \tag{5}$$

$$D = P_1A + P_2A \tag{6}$$

Using equation (5) in (6) we get:

$$D = \left(\frac{AC}{tg(183-\theta_1)}\right) + \left(\frac{AC}{tg(\theta_2 - 3)}\right) \tag{7}$$

(7) gives us:

$$AC = \frac{D \cdot tg(183-\theta_1) \cdot tg(\theta_2 - 3)}{tg(183-\theta_1) + tg(\theta_2 - 3)} \tag{8}$$

The right-angled triangle P_1AC gives us:

$$P_1C = \frac{AC}{\sin(183-\theta_1)} \tag{9}$$

$$P_1C = \frac{D \cdot tg(183-\theta_1) \cdot tg(\theta_2 - 3)}{\left(tg(183-\theta_1) + tg(\theta_2 - 3)\right) \cdot \sin(183-\theta_1)}$$

The right-angled triangle P_1BC gives us:

$$\sin(183-\theta_1) = \frac{BC}{P_1C} \tag{10}$$

$$\cos(183-\theta_1) = \frac{P_1B}{P_1C} \tag{11}$$

Replacing (9) in (10) and (11) and taking into account that $x = BC$ and $y = P_1B$ we get:

$$x = \frac{D \cdot tg(183-\theta_1) \cdot tg(\theta_2 - 3) \cdot \sin(180-\theta_1)}{\left(tg(183-\theta_1) + tg(\theta_2 - 3)\right) \cdot \sin(183-\theta_1)} \tag{12}$$

$$y = \frac{D \cdot tg(183-\theta_1) \cdot tg(\theta_2 - 3) \cdot \cos(180-\theta_1)}{\left(tg(183-\theta_1) + tg(\theta_2 - 3)\right) \cdot \sin(183-\theta_1)} \tag{13}$$

Taking into account Fig.4 and (9), (12) and (13), the horizontal distance (P_1C), between theodolite P_1 and the target can be expressed as:

$$P_1C = D \cdot \frac{\sin(183-\theta_2)}{\sin(\theta_1 - \theta_2)} \tag{14}$$

And the coordinates of the target, related to the reference position, become:

$$x = x_1 + \frac{D \cdot \sin(183 - \theta_2) \cdot \sin\theta_1}{\sin(\theta_1 - \theta_2)};$$
$$y = y_1 + \frac{D \cdot \sin(183 - \theta_2) \cdot \cos\theta_1}{\sin(\theta_1 - \theta_2)}; \quad (15)$$
$$z = z_1 + \frac{D \cdot \sin(183 - \theta_2) \cdot tg\gamma_1}{\sin(\theta_1 - \theta_2)}$$

in which $x_1=0$, , $y_1=0$ and $z_1=14.093$ are the initial coordinates of the position of P_1 cinetheodolite, and γ_1 is the vertical angle of the sighting axis of P_1 cinetheodolite in relation to the horizontal plan.

2.4 Reports of objective evaluation of the firing activities. According to the category of firing activities that are being evaluated, the EOTS-F system uses different configurations and sets of dedicated programs. When evaluating surface-to-air missile firing activities, the sequences of spatial coordinates obtained by the TV cinetheodolites make up the trajectory of the target, the sequences of spatial coordinates obtained by the IR cinetheodolites make up the trajectory of the missile, and by using the set of TRAM (TRAjectory Measurement) programs, we get the relative distance between them.

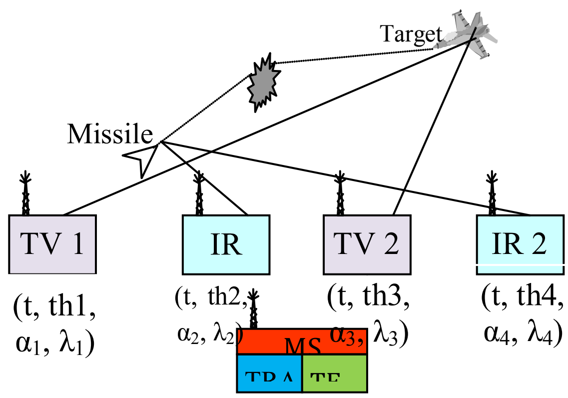

FIG.5 The standard configuration of the EOTS-F system in evaluating SAM firing activities

When evaluating artillery-firing activities, only the TV cinetheodolites are used and they determine the trajectory of the target. The input data in the evaluation process are the files containing position data and the images recorded on video tape in the same trigger as the moments of the data collection. By running the set of TES (Tracer Evaluation System) programs, a complete report with the images of all the projectile bursts in the plan of the target is obtained, with calculations of the average point of the firings and the marks according to the reckoners in the evaluation handbooks.

3. DEVELOPING EVALUATION SYSTEMS FOR FIRING ACTIVITIES

The main directions in the evolution of the equipment for the evaluation of the firing activities are:

- designing new scoring systems specific to the recently developed target planes;
- modernizing the EOTS-F system.

Given its general characteristics, the high precision and the possibilities to evaluate all categories of firing activities, it is quite appealing to refit the EOTS-F system with the latest equipment that will allow, besides accomplishing the initial functions at a high level of quality and configurability, the accomplishment of new functions, such as simultaneously tracking two targets and two missiles or tracking the air-to-air missiles of the Air Force.

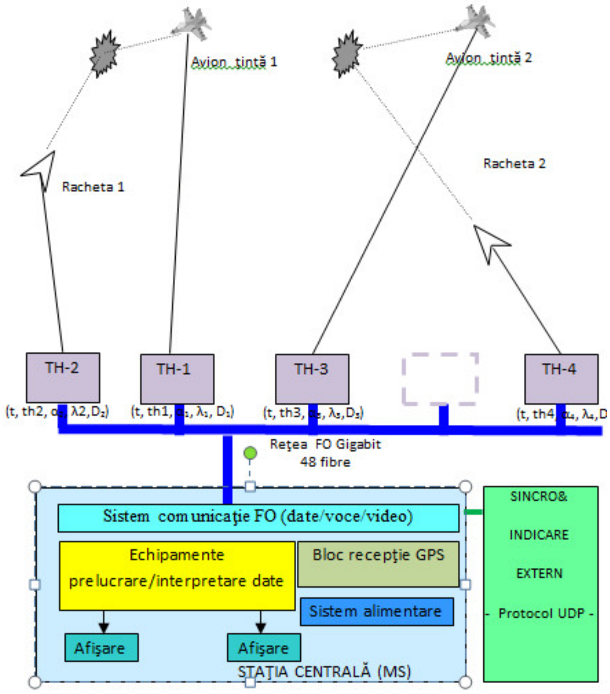

FIG.6 Evaluating firing activities on two targets in the modernized configuration

The refitting program has in view incorporating certain new pieces of equipment such as the total or partial replacement of some pieces of equipment, sensors, communication or computation blocks that are part of both the master station and the cinetheodolites. The possibilities of evaluation are enhanced by introducing some measuring devices for the *Laser Range Finder* distance and some high-speed video cameras fitted along the main sighting telescope principal of the cinetheodolites.

Operating at a higher frequency, the EOTS-F complex can collect a higher quantity of synchronized data and images at reduced intervals, which will increase the accuracy of the evaluation. The figure below shows the information leap of the measuring system after going through the modernization process.

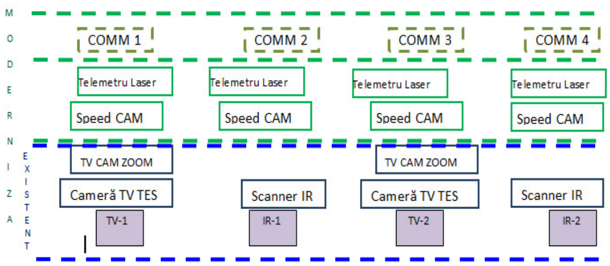

FIG.7 The modernization of the EOTS-F system at the level of the primary data sources

In this configuration, the system evaluates the firing activities and raises the complexity level of the firing scenarios.

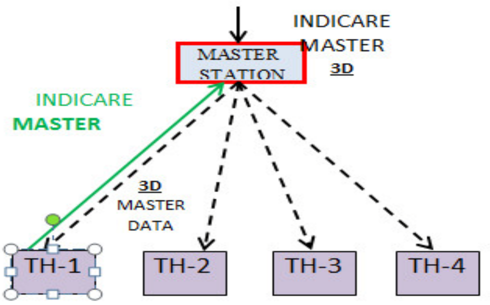

FIG.8 MASTER-SLAVE working levels for the EOTS-F system

In addition, the modernized system has the possibility to track a point within the area of the firing range after the external synchronized indication of its GPS coordinates. The indication is necessary in case the initial evolution of the target is outside the coverage of the EOT-S system, and there is subsequent entry in the combat area, where the evaluation of the firing activity takes place.

4. CONCLUSIONS & ACKNOWLEDGMENT

The existing evaluation systems constitute a good foundation on which further development of the future evaluation means can be built. All future improvements have the meaning to evaluate precisely actual and future SBAD systems. Optical and digital performances of the modernized evaluation system will be good enough to observe, analyze and evaluate live firings using even small missiles, like air-to-air missiles from distances up to 20 kilometers.

Training is a building block of any ground based air defense capability and, within it, the objective evaluation of the real firings constitutes the core tool that provides realistic view on the level of training, as well as the status of the equipment. Having this in mind, maintaining and enhancing the capabilities to evaluate the real firings should be a permanent concern for the decision-makers, in order to provide the fighters with the appropriate and unbiased feedback of their performance.

REFERENCES

[1] *Manual of P.O.S.-1 Device for control Air Defense Artillery De-phased Firings*. Capu Midia;
[2] *** CB GBP 002 Master station Vol., 1996;
[3] *** *CB AAV 002 EOTS-F cinetheodolite system* – System description, Part 1-2, Volume 1-4, 1996;
[4] Marius RĂDULESCU, Vasile ŞANDRU, *Integration of the VSHORAD Missile with the Small Caliber Anti-Aircraft Guns, a Way for an Increasing Efficacity*, Braşov, AFASES 23-25 mai 2013;
[5] Şandru, V., *Emerging Aspects in the Process of Modernizing Integrated Aerospace Systems*, Review of the Air Force Academy, Vol X, No 2 (21), pp. 25-30, Braşov, 2012;
[6] Vasile ŞANDRU, *The Current Stage of Air Defense Systems' Structure and Performances. S.A.M. Systems Comparative Analysis in Romanian Inventory*, Review of the Air Force Academy, Vol. XI, No 1(23)/2013, pp..107-112 Braşov, 2013.